Investigating Efficiencies in the Search for Compressed Supersymmetry with a Soft Tau Lepton and a Highly Energetic ISR Jet

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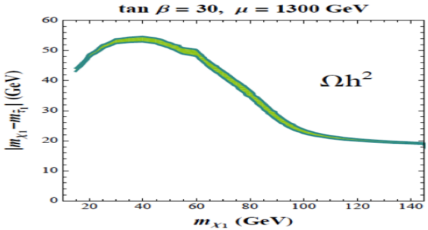
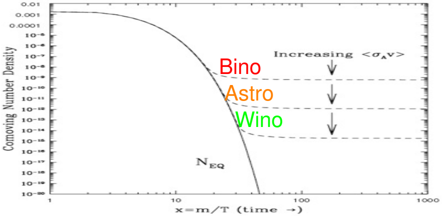
Particle Physics, Cosmology, and Dark Matter

- *Supersymmetry* provides a dark matter (DM) candidate particle in the form of the lightest neutralino ($\tilde{\chi}_1^0$).
- If the DM particle is mostly Bino (Z-like), this gives an overabundance of DM in the universe; annihilation cross section is small.
- Introducing *coannihilation* into the model brings the DM relic density down and closer to the value measured by astronomers.
- The DM relic density is extremely sensitive to the mass difference between the stau ($\tilde{\tau}$) and the $\tilde{\chi}_1^0$ $\rightarrow$ motivates a search for compressed spectra.

http://arxiv.org/pdf/1205.5842v1.pdf





Jungman *et al* hep-ph/9506380

$$\Omega h^2 \propto \frac{1}{<\sigma v>_{\mathrm{A}} + <\sigma v>_{\mathrm{CA}}};$$

$$<\sigma v>_{\mathrm{CA}} \sim e^{-\Delta m}$$

Probing the Stau-Neutralino Coannihilation Region at the LHC with a soft tau lepton and an ISR jet

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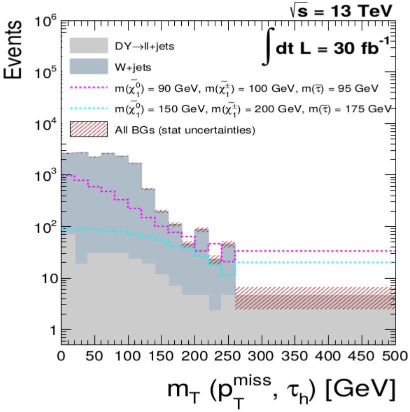


- This search targets compressed-mass spectra, where the mass difference between $\tilde{\tau}$ and $\tilde{\chi}^0_1$ is small.
- Since the mass difference is small, we introduce an ISR jet to boost the system, provide large E_T^{miss}, and aid in the acceptance of a "soft" τ.

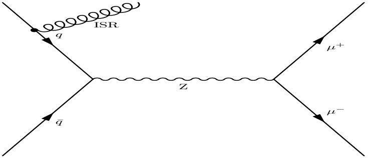
$$\tilde{\chi}_1^+\tilde{\chi}_1^- j \rightarrow \tilde{\tau}^+\tilde{\tau}^- \nu\nu j \rightarrow \tau^+\tau^- \nu\nu\tilde{\chi}_1^0\tilde{\chi}_1^0 j$$

- Search strategy:
  - $p_{\mathrm{T}}^{\mathrm{ISR}}(j) > 100$ GeV
  - $E_{\mathrm{T}}^{\mathrm{miss}} > 230$ GeV
  - $20 < p_{\mathrm{T}}(\tau_h) < 40$ GeV
  - Veto other leptons and b-jets.

Defining the Z$\rightarrow$ ($\mu^+\mu^-$)+ISR Control Region

$$N_{\rm SR} = \sigma \cdot L_{\rm int} \cdot \epsilon_{\tau_h} \cdot \epsilon_{E_{\rm T}^{\rm miss}} \cdot \boxed{\epsilon_{\rm ISR}}$$

Cuts for the $\mathrm{Z} \rightarrow (\mu^+\mu^-) + \mathrm{ISR}$ ***CR***
$N(\mu)$=2
Isolated muon $p_{\rm T} > 30$ GeV
$\lvert\eta(\mu)\rvert < 2.1$
Q_{μ_1}*$Q_{\mu_2} < 0$ [OS]
80 GeV $< m(\mu,\mu) <$ 100 GeV
$\lvert\eta(j)\rvert < 2.4$
$N(j) \geq 1$
Leading jet $p_{\rm T} \geq$ *100 GeV*
Trigger: Single isolated μ $p_{\rm T} \geq 24$ GeV

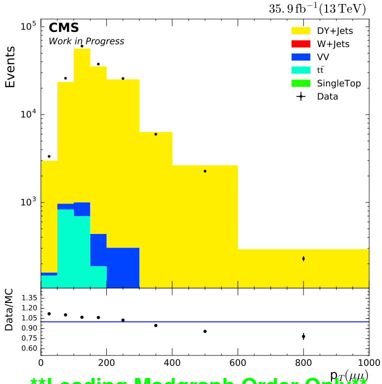


Get a handle on $\epsilon_{\rm ISR}$.

- Identification of muons is clean.
- There is no real $E_T^{\rm miss}$.
- We removed jet overlap with muons.
- These two measures guarded against jets faking as leptons.

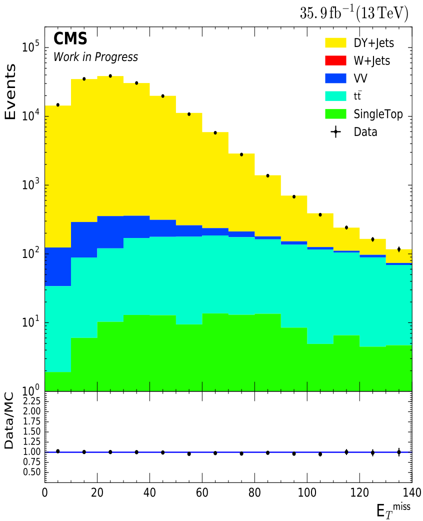
Defining the Boson Boost Weights

- Add *vectorially* the $\vec{p}_T$ of the muons; this is the Z boost $\left(\vec{Z}_T\right)$ by conservation of momentum.
- $\vec{Z}_T$ is mismodeled in MC; we derive weights to correct the distributions in simulation.

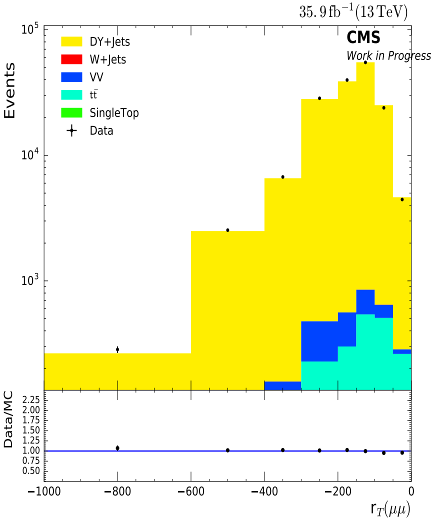


Leading Madgraph Order Only

Bin	Boost Wgt
0-50 GeV	1.1192
50-100 GeV	1.1034
100-150 GeV	1.0675
150-200 GeV	1.0637
200-300 GeV	1.0242
300-400 GeV	0.9453
400-600 GeV	0.8579
600-1000 GeV	0.7822



$E_{\mathrm{T}}^{\mathrm{miss}}$ with Boost Wgt



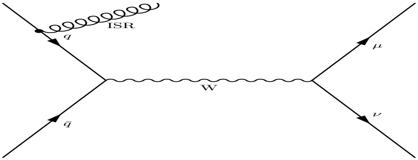
$\vec{r}_{\mathrm{T}} = -\left(\vec{E}_T^{\mathrm{miss}} + \vec{Z}_{\mathrm{T}}\right)$ with Boost Wgt

The distributions nicely model the data after correcting simulation with the boost weights.

Defining the W$\rightarrow (\mu\nu) + \mathrm{ISR}$ Control Region

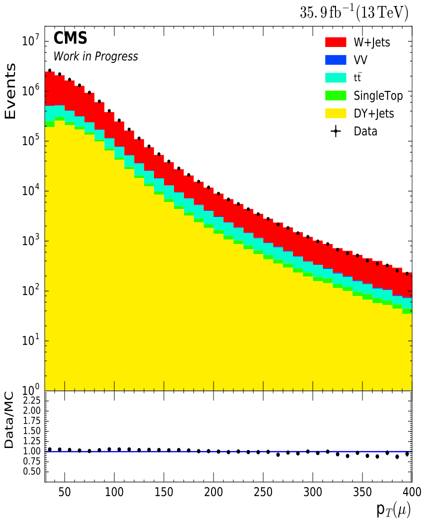
$$N_{\mathrm{SR}} = \sigma \cdot L_{\mathrm{int}} \cdot \epsilon_{\tau_h} \cdot \boxed{\epsilon_{E_{\mathrm{T}}^{\mathrm{miss}}}} \cdot \epsilon_{\mathrm{ISR}}$$

Cuts for the $\mathrm{W} \rightarrow (\mu\nu) + \mathrm{ISR}$ ***CR***
$N(\mu)$=1
μ: tight ID
Isolated muon $\mathrm{p_T} > 30$ GeV
$\lvert\eta(\mu)\rvert < 2.1$
$E_T^{\mathrm{miss}} > 50$ GeV
60 GeV $< m_T(\mu, E_T^{\mathrm{miss}}) <$ 100 GeV
$\lvert\eta(j)\rvert < 2.5$
$N(j) \geq 1$
$N(\mathrm{b-jets}) = 0$
First leading jet $\mathrm{p_T} \geq 50$ GeV
Trigger: Single isolated μ $\mathrm{p_T} \geq 24$ GeV

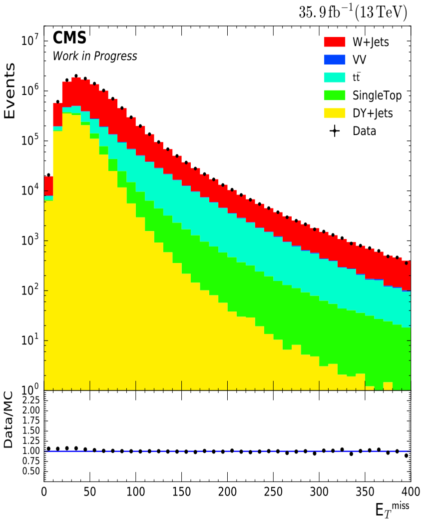


Validate the boost weights and $E_{\mathrm{T}}^{\mathrm{miss}}$ modeling.

- This event has *real* $E_{\mathrm{T}}^{\mathrm{miss}}$.
- The boost weights are the same as from the Z-region.
- We removed jet overlap with muons.
- We vetoed electrons and taus.



$p_{\mathrm{T}}(\mu)$ with Boost Wgt



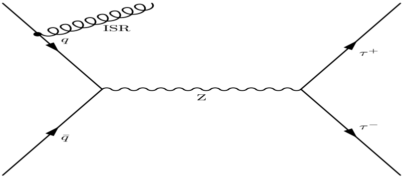
$E_{\mathrm{T}}^{\mathrm{miss}}$ with Boost Wgt

The distributions nicely model the data after correcting simulation with the boost weights. The $E_{\mathrm{T}}^{\mathrm{miss}}$ is also well-modeled.

Defining the Z$\rightarrow (\tau^+\tau^-) + \mathrm{ISR}$ Control Region

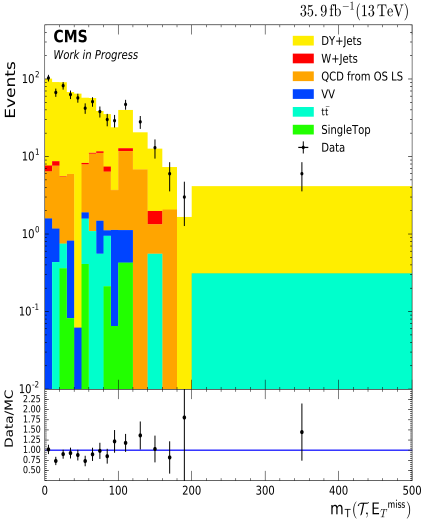
$$N_{\mathrm{SR}} = \sigma \cdot L_{\mathrm{int}} \cdot \boxed{\epsilon_{\tau_h}} \cdot \epsilon_{E_T^{\mathrm{miss}}} \cdot \epsilon_{\mathrm{ISR}}$$

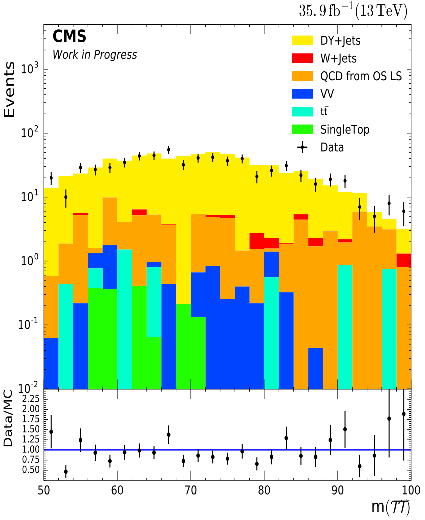
Cuts for the $\mathrm{Z} \rightarrow (\tau^+\tau^-) + \mathrm{ISR}$ ***CR***
$N(\tau) \geq 2$
Isolated tau $\mathrm{p_T} > 60$ GeV
$\lvert\eta(\tau)\rvert < 2.1$
Loose against electron MVA veto
ID(e): Loose, ID(μ): Tight
Tight muon veto
50 GeV $< m(\tau, \tau) <$ 100 GeV
$N(j) \geq 1$
Leading jet $\mathrm{p_T} \geq 100$ GeV
$N(\mathrm{b-jets}) = 0$



Get a handle on $\epsilon_{\tau\mathrm{ID}}$.

- Tau Discriminator: Tight MVA
- Trigger: Double isolated τ $\mathrm{p_T} \geq 35$ GeV
- QCD: SS ditau events scaled by $R_{OS/SS} = 1.2$ (measured in region with $m(\tau, \tau) > 100$ GeV).
- We apply the recommended 5% correction to $\epsilon_{\tau\mathrm{ID}}$.





Agreement is observed, thus validating the modeling of tauID efficiency in simulation.

Summary and Conclusions

- Compressed spectra SUSY, such as the $\tilde{\tau}$-$\tilde{\chi}_1^0$ coannihilation region, is important to DM and cosmology. Compressed regions are difficult to probe at the LHC.
- The ISR + soft-τ_h + E_T^{miss} search channel allows to probe **previously inaccessible** phase space.
- Understanding the modeling of initial state radiation, and its correlation with the lepton and E_T^{miss}, is a key aspect of this search.
- Studies on Z$\rightarrow (\mu^+\mu^-) + \mathrm{ISR}$ resulted in the boson boost weights.
  - The efficiency ϵ_{ISR} is well-understood.
  - After further study into jet resolution, ϵ_{MET} is also well-understood.
- Those boson weights (and modeling of the $E_{\mathrm{T}}^{\mathrm{miss}}$) were validated on a region of W$\rightarrow (\mu\nu) + \mathrm{ISR}$.
- Studies on Z$\rightarrow (\tau^+\tau^-) + \mathrm{ISR}$ showed that $\epsilon_{\tau\mathrm{ID}}$ is well-understood.
- We understand the efficiencies necessary to complete this analysis, and a publication is right around the corner.